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THE FLIGHT TELEROBOTIC SERVICER: NASA's FIRST OPERATIONAL SPACE ROBOT

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INTRODUCTION

The application of robotics to operations in space promises great benefits in extending the capability of man in exploration. Robotics is highly relevant to NASA's long-range vision of establishing a manned base on the moon, and later in exploring the surface of mars. An interplanetary voyage is of a different order of complexity from traveling to earth's moon because rapid return to earth in the event of trouble would be impossible. For such a mission involving humans, it would be prudent to first establish an operational base at the destination complete with an earth return capability. Humans would not begin their voyage until the remote base was assembled and known to be operational. Assembly and maintenance of such a base might be performed by robots that would work with a high degree of autonomy. Alternatives to the exploration of mars by direct human presence are under consideration by both the United States and the Soviet Union. In these concepts, autonomous surface vehicles would navigate the planet performing a variety of detailed exploratory functions such as mapping, seismic measurements, sample collection and analysis. Both of these approaches to the exploration of mars depend to a high degree on the ability of robotic machinery to perform complex functions without real-time human direction. Closer to home and in time, robotics will begin to play a role in space operations in the construction and maintenance of Space Station Freedom. This paper will introduce the Flight Telerobotic Servicer Project as an element of the Space Station Freedom, and discuss its objectives and some special challenges it faces.

THE NEED FOR ROBOTICS IN BUILDING THE SPACE STATION

The Space Station Freedom will be assembled on orbit through a sequence of 26 shuttle launches, each bringing a full load of truss members, modules, and work fixtures. The assembly process will be performed by astronauts wearing pressure suits - termed Extra-Vehicular Activity or EVA. The Shuttle's remote manipulator arm (RMS) will provide mobility for both crew and equipment. It is estimated that several hundred hours of astronaut EVA time will be required to complete assembly of the initial configuration of the space station.

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Presently, EVA is not performed during the first two days of shuttle flights to allow the crew to acclimate to weightlessness and the tendency toward disorientation which EVA makes worse. After the two day adjustment period, each EVA session requires two hours of preparation time before the actual EVA operations begin, and the useful operation time is limited to about 7 hours due to the physical demands of flexing a fairly stiff pressure suit and exhaustion of consumables such as cooling water. New suit technology employing more compliant joints and closed cooling systems are currently being investigated to reduce these limitations. Each EVA session places the crew at some degree of risk from failure of one of the essential parts of the EVA system. These systems are designed to be highly reliable, but as the number of EVA hours worked increases, even small failure probabilities multiply and become a significant risk in the long term.

Considering all of these factors, it can be seen that robotic machines, designed to perform a significant portion of the space station assembly, would reduce the requirement for manned EVA, thereby providing significant gains in productivity and safety for the crew. This is one of the principle objectives of the FTS Project. The method of controlling the telerobot will initially be teleoperation where a human operator within a pressurized module of the space station continuously directs every step of the robot's operation and performs all object recognition and maneuver planning.

OTHER USES FOR A SPACE TELEROBOT

There are important applications for robotics beyond assembly and maintenance in proximity of the Space Station. When attached to a suitable transfer vehicle such as the Orbital Maneuvering Vehicle (OMV), the FTS will be capable of visiting spacecraft in orbits which the Shuttle, and hence astronauts, cannot presently achieve. This opens the new possibility of performing remote servicing operations on space assets without being limited by the shuttle operational envelope. However, because of the inherent communications delays and likely bandwidth limitations associated with such a mission, a different operational mode for the FTS will be required. Called supervised autonomy, this mode must provide the capability for the FTS to perform many operations with little or no human direction. The human supervisor would intervene only at planned stages of the operation to confirm the success of prior steps performed autonomously by the robot, and to confirm readiness to proceed to the next step. Autonomous operation of the telerobot would also be valuable in the space station assembly and maintenance application because it would relieve the human operator from continuously directing every action to be performed, thereby freeing the operator to do other tasks.

THE TECHNOLOGY CHALLENGE

Achieving autonomous control capability will require that most of the planning and sensor interpretation functions that are done by a human operator in the teleoperation case must now be performed by sensors and processing aboard the telerobot. A substantial on-board database is also needed to provide rapid access to geometric descriptions of the workspace, procedures to be executed, and criteria for success and failure for each step. The algorithms and machinery required to support autonomous operation of a robot are currently being explored in research laboratories, and much work is needed to develop them into operational capabilities. Therefore, autonomous operation is considered a long-term goal for the FTS, and initial capabilities will concentrate on teleoperation. This initial capability will include sensing and processing to support bilateral force reflection - a technique whereby forces and torques being exerted by the end effector are measured and used to actuate motors in the hand controller such that the operator "experiences" the forces and torques being exerted on the workpiece. This capability is needed to perform certain tasks where the ability to "feel" proper engagement is important to successful teleoperation. In addition, a few elementary forms of autonomous control will be provided, including active compliance and modes of control shared between the human operator via the work station and on-board algorithms.

But the attainment of significant degrees of autonomous control remains a long-term objective, and this implies that as robust sensing and processing techniques and hardware become available, the FTS must be upgraded to accommodate them. The FTS design anticipates this requirement, and employs an architecture that will facilitate the refinement or the replacement of function when required. The selected architecture is an emerging standard called NASREM developed jointly by NASA and the National Institute for Standards and Technology. [1]

THE OPERATIONAL CHALLENGE

There are two critical questions that need to be considered: The first is, "what can a telerobot do in space?" Our operational experience to-date for tasks involving a high degree of dexterity is that very little has been done robotically in space, and so a fundamental credibility must be established. The FTS Project has responded to this through a forum called the Mission Utilization Team whose charter is to analyze a representative suite of space station assembly tasks. A process of task decomposition develops the detailed sequence of steps required to perform a given task and identifies the needs for mobility, utilities at specific locations, special fixtures, and use of standard facilities such as the Remote Manipulator System. The analysis proceeds down to the geometric descriptions of the work space and the kinematics

of the FTS. Positioning of the robot and the objects it works with are worked out in time sequence and dynamic envelope clearance is checked at every incremental position through the entire task. The process is laborious and rigorous, and yields a good initial assessment of feasibility. However, full-scale mockup testing will be required to ultimately prove the ability of the system to accomplish the task.

The FTS Project includes two test flights aboard the Space Shuttle to evaluate the effectiveness of the human-machine interface and to demonstrate the ability of the telerobot to perform representative tasks. The experience gained through these flights will establish a significant degree of confidence in relying on telerobots to perform important space station assembly work.

The second question to be addressed is: "Believing that certain jobs can be performed by robots, what is the case for probable success for a specific task?" The FTS is to be an operational system that can be depended upon to perform important tasks in constructing and maintaining SS Freedom. Dependability and the required end result of accomplishment of function distinguish an operational system from an experiment in which the primary objective is information. Tasks to be performed by the FTS must have a substantial probability of working, even in the presence of difficulty. If it is not successful, then unplanned use of EVA as an alternative will come at potentially high expense in terms of the overall mission. The assurance of a high probability of success implies a significant investment in FTS reliability, diversity of ways of doing things, operations testing, and long-term technical support. Dependability in the context of operations is a quality that is not merely designed-in, but must also be earned through successful mission testing. The preparation for performing space operations using astronauts is presently a significant undertaking. Procedures and contingency plans must be developed, tested, and rehearsed thoroughly by the crew to assure that the mission will succeed even when things don't go as planned. The presence of a robot and its control station adds several new considerations to the mission planning process, including the attachment of the robot to the work site, planning & handling of reaction loads, and the interaction of the robot with other active control systems such as the shuttle or space station RMS. An effective space robotic system must include capabilities to support both mission planning and the conduct of simulations that interact with humans and other systems in a highly realistic manner.

For these purposes, the FTS Project includes the development of a trainer - a telerobot and workstation capable of operation in a 1-G environment, and which are highly representative of the FTS flight system. The project will develop mockups and simulators as required to accomplish pre-integration of the FTS with the

space station. A Robotics Development, Test, and Integration facility is also being prepared to support the testing of procedures and tooling to perform actual assembly and servicing operations and to evaluate advanced technology and control techniques. [2]

CONCLUSION

In being NASA's first general-purpose space telerobot, the FTS Project has simultaneously a significant technical challenge and a great responsibility to do the job well so that robotics becomes firmly established as an effective way to operate in space. We recognize that in being the first, a degree of skepticism must be overcome. And rightly so, because the NASA reputation for successful operations in space was not achieved by recklessly attempting untried techniques for the first time in orbit. Therefore a rigorous program is required to demonstrate the capabilities of the FTS together with it's control system and human operators to perform the actual tasks that it will be called upon to perform in orbit.

In order for FTS to achieve its long-term objectives in control autonomy, critical developments must be accomplished in the laboratory and then transferred to the FTS operational system. The research efforts sponsored by NASA should target these requirements, and the FTS Project must provide means to develop the results of these efforts into robust operational techniques and hardware. The FTS is being designed in a way to make such changes feasible, and the necessary development and integration facilities are planned to support this process. In the long term, FTS is only a beginning in applying robotic technologies to performing general physical tasks in space. It is inevitable that many robotic systems will follow, some similar to FTS in form and function, and others that are intended for quite different applications. It is our hope and commitment that the FTS will be the first positive step for robotics as an effective operational tool in spaceflight.

REFERENCES

[1] "The FTS: From Functional Architecture to Computer Architecture" R. Lumia, National Institute of Standards and Technology.

[2] "Development of a Robotics Technology Test Bed for the Flight Telerobotic Servicer Project" G. Mosier, M. O'Brien, and R. Schnurr, Goddard Space Flight Center.

FLEXIBLE ARMS

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